

**General Corrosion Resistance Assessments of AA7085,
AA7129, and Other High-Performance Aluminum
Alloys for Department of Defense (DOD) Systems Using
Laboratory Based Accelerated Corrosion Methods
and Electrochemistry**

**by Theresa A. Dillon, Elizabeth A. Charleton, Joseph P. Labukas, and
Brian E. Placzankis**

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September 2013

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14. ABSTRACT General corrosion assessments were conducted on currently used Military Specification (MILSPEC) grade aluminum alloys: AA7085-T711, AA7085-T721, and extruded AA7129-T5 in accelerated corrosion test chambers using ASTM B 117 Neutral Salt Fog (NSF) (ASTM B117–90. Standard Method of Salt Spray (Fog) Testing. <i>Annu. Book ASTM Stand.</i> 1990) and General Motors Standard 9540P (GM 9540P) (GM 9540P. <i>Accelerated Corrosion Test</i> , General Motors Engineering Standards, 1997) cyclic accelerated corrosion methods. Additional alloys proposed for possible future transitions to Department of Defense (DOD) systems—including AA2027-T351, AA2027-T851, AA7017-T651, AA7017-T7651, AA7056-T7351, and AA7056-T7651—were also evaluated. The NSF specimens were evaluated at 18-, 72-, and 168-hour (h) intervals. The GM 9540P specimens were examined at 1-, 5-, and 10-cycle intervals. Electrochemical evaluations of corrosion susceptibility for each of the alloys were performed using potentiodynamic polarization. The relative susceptibilities to general corrosion attack in comparison to current MILSPEC alloys and within their respective alloy series are discussed.					
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1. Introduction

Current Department of Defense (DOD) systems use a variety of wrought-aluminum alloys in their designs to fulfill mission needs. Among the varieties used are heat-treatable 2000-, 6000-, and 7000-series alloys and strain hardened non heat-treatable 5000-series alloys. All of these materials have their respective merits in areas such as mechanical performance, ballistic performance, weldability, corrosion resistance, availability, and price. The focus alloys of this research are currently used AA7085 and AA7129; and emerging alloys such as AA2027, AA7017, and AA7056 in various tempers that were either not registered, or were not originally considered for inclusion in previous studies. AA7085 is currently qualified as an armor plate material under two distinct tempers, T711 and T721; and is also known by the designations AA7085-T7E01 (Type A) and AA7085-T7E02 (Type B) that were recently established under the new Military Specification (MILSPEC): MIL-DTL-32375(1), “Armor Plate, Aluminum Alloy, 7085, Unweldable Appliqué.” The AA7085 plates are intended only for appliqué (bolt-on) applications and are currently not considered weldable. The other alloy currently used in U.S. Military applications is AA7129-T5. Although no specific MILSPEC exists for AA7129-T5, extrusions of this alloy are used for internal components of canister-based artillery munitions and also commercially in automotive applications such as lightweight bumpers (2). Other alloys included in this study are AA2027 in T351 and T851 tempers, AA7017 in T651 and T7651 tempers, AA7056 in T7351 and T7651 tempers. AA7017 has been successfully used in European military ground systems and AA2027 and AA7056 have been used in various commercial and military aviation applications.

Tables 1–3 list the alloying elements and mechanical properties for the MILSPEC qualified armor alloys and for the proposed alloys. It is important to note that the mechanical properties listed for the current MILSPEC qualified armor alloys in table 2 represent typical values and the actual burden for these alloys ultimately lies with meeting or exceeding the minimum acceptance velocities, as stated in the specification. Actual mechanical properties for these alloys are often significantly greater as delivered from the manufacturer. The mechanical properties listed for the remaining alloys are based upon openly available industry reported values found in manufacturer specifications.

Table 1. Chemical composition requirements of MILSPEC and prospective aluminum armor alloys (%) (3).

<i>Element</i>	Registered International Designation								
	2027	2139	2195	2519	7017	7039	7056	7085	7129
Silicon	0.12 max	0.10 max	0.12 max	0.25 max	0.35 max	0.30 max	0.10 max	0.06 max	0.15 max
Iron	0.15 max	0.15 max	0.15 max	0.30 max	0.45 max	0.40 max	0.12 max	0.08 max	0.30 max
Copper	3.9 - 4.9	4.5 - 5.5	3.7 - 4.3	5.3 - 6.4	0.20 max	0.10 max	1.2 - 1.9	1.3 - 2.0	0.5 - 0.9
Manganese	0.5 - 1.2	0.2 - 0.6	0.25 max	0.10 - 0.50	0.05 - 0.50	0.10 - 0.40	0.20 max	0.04 max	0.10 max
Magnesium	1.0 - 1.5	0.2 - 0.8	0.25 - 0.80	0.05 - 0.40	2.0 - 3.0	2.3 - 3.3	1.5 - 2.3	1.2 - 1.8	1.3 - 2.0
Chromium	-	0.05 max	-	-	0.35 max	0.15 - 0.25	-	0.04 max	0.10 max
Nickel	-	-	-	-	0.10 max	-	-	-	-
Zinc	0.2 max	0.25 max	0.25 max	0.10 max	4.0 - 5.2	3.5 - 4.5	8.5 - 9.7	7.0 - 8.0	4.2 - 5.2
Titanium	0.08 max	0.15 max	0.10 max	0.02 - 0.10	0.15 max	0.10 max	0.08 max	0.06 max	0.05 max
Vanadium	-	0.05 max	-	0.05 - 0.15	-	-	-	-	0.05 max
Zirconium	0.05 - 0.15	-	0.08 - 0.16	0.10 - 0.25	0.10 - 0.25	-	-	0.08 - 0.15	-
Gallium	-	-	-	-	-	-	-	-	0.03 max
Lithium	-	-	0.8 - 1.2	-	-	-	-	-	-
Silver	-	0.15 - 0.6	0.25 - 0.6	-	-	-	-	-	-
Others (each)	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max
Others (max)	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max
Aluminum	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder

Table 2. Minimum mechanical acceptance requirements for 2000-series MILSPEC aluminum armor alloys and vendor data for prospective alloys (3-5).

Property/Alloy	2027-T351	2027-T851	2139-T8	2195-T841 (BT)	2519-T87
Yield Stress (ksi)	52	68	64	63	58
Ultimate Stress (ksi)	68	74	67	71	68
Elongation (%)	14	11	9	9	7
Density (g/cm ³)	2.79	2.79	2.80	2.71	2.82

Table 3. Minimum mechanical acceptance requirements for 7000-series MILSPEC aluminum armor alloys and vendor data for prospective alloys (1, 3, 6, 7).

	Aluminum Alloy					
	2027	2060	6055	7017	7056	7129
Element						
Silicon	0.12 max	0.07 max	0.6 - 1.2	0.35 max	0.10 max	0.15 max
Iron	0.15 max	0.07 max	0.3 max	0.45 max	0.12 max	0.30 max
Copper	3.4 – 4.9	3.4 – 4.5	0.50 – 1.0	0.20 max	1.2 – 1.9	0.50 – 0.9
Manganese	0.50 – 1.2	0.10 – 0.50	0.10 max	0.05 – 0.50	0.20 max	0.10 max
Magnesium	1.0 – 1.5	0.6 – 1.1	0.1 – 1.1	2.0 – 3.0	1.5 – 2.3	1.3 – 2.0
Chromium	-	-	0.20 – 0.30	0.35 max	-	0.10 max
Zinc	0.20	0.30 – 0.50	0.55 – 0.9	4.0 – 5.2	8.5 – 9.7	4.2 – 5.2
Titanium	0.08	0.10 max	0.10 max	0.15 max	0.08 max	0.05 max
Zirconium	0.05 – 0.15	0.05 – 0.15	-	0.10 – 0.25	0.05 – 0.15	-
Vanadium	-	-	-	-	-	0.05 max
Lithium	-	0.6 – 0.9	-	-	-	-
Silver	-	0.05 – 0.5	-	-	-	-
Gallium	-	-	-	-	-	0.03 max
Others (each)	0.05	0.05	0.05	0.05	0.05	0.05
Others (max)	0.15	0.15	0.15	0.15	0.15	0.15
Aluminum	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder

Though corrosion resistance is certainly a desirable characteristic for any material, it is an attribute that is often overlooked or underestimated by designers of weapon systems or platforms. A variety of sources exist for referencing corrosion resistance and performance of aluminum alloys; such as the ASM Metals Handbook (8), Corrosion Engineering by Fontana (9), and a myriad of individual papers and reports from a variety of institutions such as NACE (10) The Minerals, Metals, and Materials Society (TMS) (11), and JOM (12), and previous DOD Corrosion Conferences. The goal of this research is to expand upon previous work (13) in order to supply basic accelerated corrosion data from two of the most widely used laboratory based accelerated corrosion methods (ASTM B117 [14] and General Motors [GM] 9540P [15]). Data from these tests should be interpreted with caution as they are qualitative assessments that can be used to support the overall design of a platform and should not stand alone. Corrosion vulnerability data from other sources such as the Aberdeen Test Center Automotive Test Track, long-term outdoor exposures, corrosion data from actual fielded platforms, and even electrochemical interrogation carried out in the laboratory should play a role in the final design decision process. Integration factors such as conversion coatings, primers, topcoats, and their associated contexts within their mission roles, will ultimately decide their usefulness. This study represents a snapshot of the alloys currently in use and compares them in relation to prospective future and untested alloys.

2. Experimental Procedure

This study assesses the inherent corrosion resistances of unprotected aluminum alloys currently in use, or proposed for use by the U.S. DOD. A wide selection of aluminum alloys were chosen from ground, marine, and aviation based systems. The alloys of various tempers (listed in numerical order) were: AA2027-T351, AA2027-T851, AA7017-T651, AA7017-T7651, AA7056-T7351, AA7056-T7651, AA7085-T711, and AA7085-T721. Broad ranges of applications and operational environments led to multiple tempers among some of the different alloys.

The actual aluminum specimens were cut to 1.75 in \times 1.5 in \times 0.25 in (l \times w \times t) nominal dimensions using a water-cooled Buehler Abrasimet* saw. They were then finished to a 600 grit surface via metallographic grinding techniques. Following grinding, the specimens were cleaned and rinsed using acetone, allowed to air dry, organized in racks similar to the one shown in figure 1, and then placed into the respective corrosion chambers. In order to visually assess and characterize the corrosion, all specimen images were acquired via flatbed scans at 1200-dpi optical resolution at their respective observation intervals.



Figure 1. Corrosion rack configuration used for Neutral Salt Fog (NSF) and GM 9540P exposures.

A Harshaw Model 410 test chamber was used for NSF testing and an Atotech Model CCT-P series chamber was used for cyclic corrosion testing. The NSF operating parameters were in accordance with ASTM B 117 at 95 °F with saturated humidity and an atomized fog of 5% NaCl-solution. The observation and scanning intervals for the specimens in NSF were 18, 72, and 168 h. The GM 9540P cyclic accelerated corrosion test consisted of 18 separate stages that included the following: saltwater spray using 0.9% NaCl, 0.1% CaCl₂, 0.25% NaHCO₃ test solution, high humidity, drying, ambient, and heated drying. The environmental conditions and duration of each stage for one complete cycle are provided in table 4.

* The Buehler Abrasimet saw is a registered trademark of Buehler.

Table 4. GM 9540P cyclic corrosion test parameters (15).

Interval	Description	Time (min)	Temperature ($\pm 3^{\circ}\text{C}$)
1	Ramp to Salt Mist	15	25
2	Salt Mist Cycle	1	25
3	Dry Cycle	15	30
4	Ramp to Salt Mist	70	25
5	Salt Mist Cycle	1	25
6	Dry Cycle	15	30
7	Ramp to Salt Mist	70	25
8	Salt Mist Cycle	1	25
9	Dry Cycle	15	30
10	Ramp to Salt Mist	70	25
11	Salt Mist Cycle	1	25
12	Dry Cycle	15	30
13	Ramp to Humidity	15	49
14	Humidity Cycle	480	49
15	Ramp to Dry	15	60
16	Dry Cycle	480	60
17	Ramp to Ambient	15	25
18	Ambient Cycle	480	25

In accordance with the GM 9540P specification, the cyclic chamber was calibrated with standard steel mass loss calibration coupons to ensure consistent corrosivity levels. Although the GM 9540P protocol was developed for automotive steel substrates, previous studies (16) have shown that the cyclic nature of the exposure and the electrolyte used can have a significant corrosion impact particularly among the 2000- and 7000-series alloys. The observation and scanning intervals for the GM 9540P specimens were 1, 5, and 10 cycles.

At the conclusion of the accelerated corrosion testing, excess corrosion products were removed from the specimen surfaces by etching in an aqueous solution of 0.20 M CrO_3 and 0.76 M H_3PO_3 for 5–15 minutes (min) at 90–100 $^{\circ}\text{C}$ in accordance with ASTM G 1, C.1.1 (17) to further reveal the extent of damage to the underlying metallic surface. Cleaned specimens were imaged optically using a 1200-dpi flatbed scanner.

Polarization curves were collected using a Gamry Reference 600 potentiostat. A Princeton Applied Research flat cell comprised an aluminum alloy as the working electrode, a platinum-coated mesh¹ as the counter electrode, a saturated calomel reference electrode and quiescent 3.5% aqueous NaCl solution. The aluminum alloys were polished to 600 grit with silicon carbide paper, rinsed thoroughly with deionized (DI, 18 M Ω cm), and dried with a stream of nitrogen. Alloys were then polarized between -0.25 and $+0.5$ V of the open circuit potential (OCP). A

¹ Intrepid Industries Inc.

total of five scans from different spots of the alloy surface were collected in freshly prepared electrolyte solutions (i.e., each spot used a fresh solution and a clean flat cell). The sample with an OCP nearest the average OCP of the five scans was used as the representative polarization for a particular alloy.

3. Results

3.1 2000-Series Alloys

The 2000-series alloys are often utilized in DOD for aviation and armor applications for their high strength and excellent performance in ballistics. As expected, after just 18 h of NSF exposure, it was readily apparent that the alloys containing the highest copper alloying additions exhibited the greatest corrosion, mainly from pitting attack. The alloy 2024-T3 has been used for decades in both U.S. Navy and U.S. Air Force aircraft for its excellent mechanical properties. The T351 and T851 tempers of AA2027 are candidates for possible incorporation into MIL-DTL-46192C or MIL-DTL-32341 armor plate specifications. The scanned images in figures 2–5 show the relative corrosion susceptibility of the two AA2027 tempers during the course of the salt fog and cyclic corrosion exposures. Surface regions that differ or appear less corroded near the lower edges of some samples are artifacts created from a locally different environment due to the configuration of the sample holder.

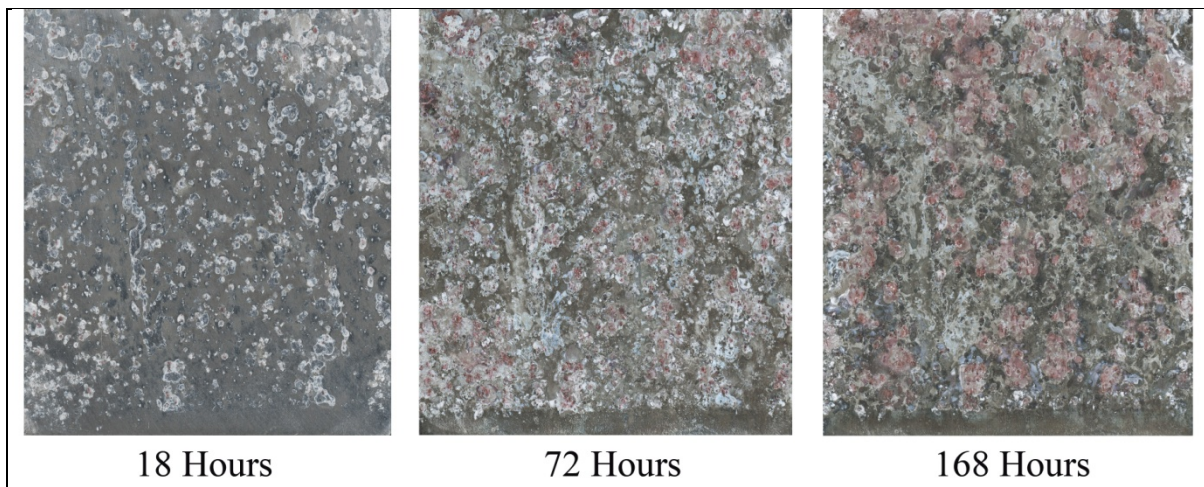


Figure 2. AA2027-T3 after NSF.

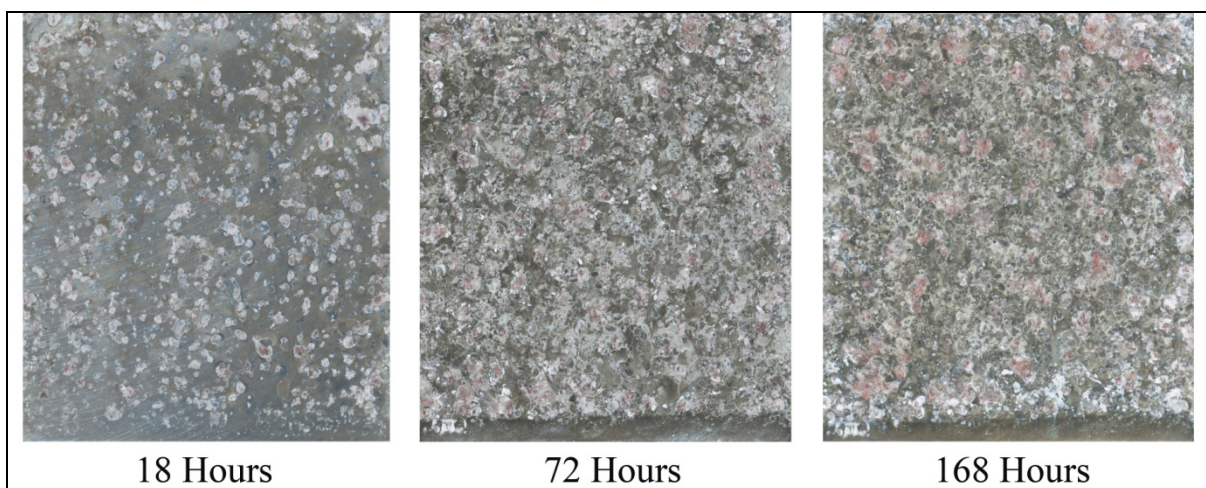


Figure 3. AA2027-T8 after NSF.

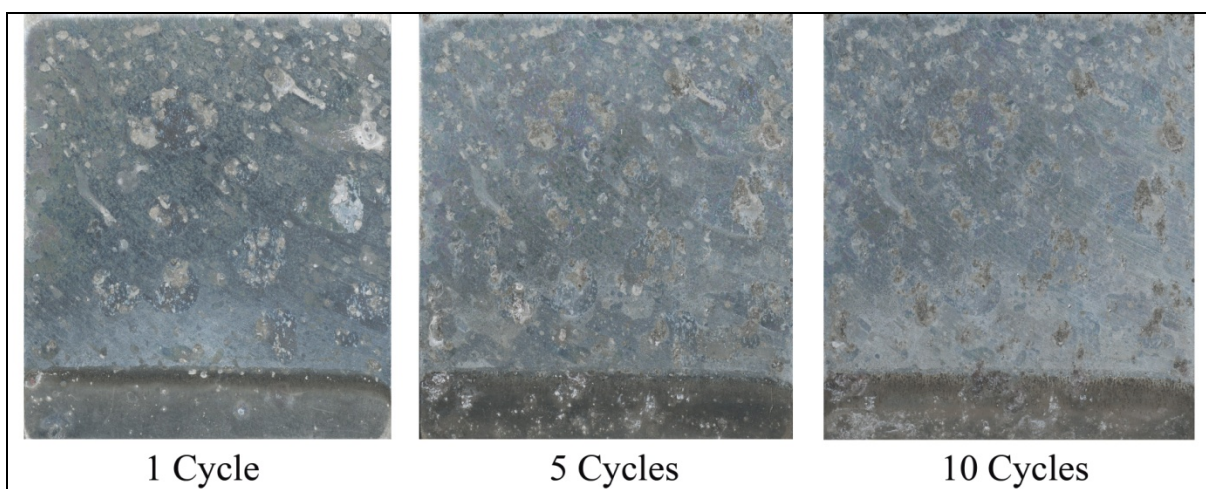


Figure 4. AA2027-T3 after GM 9540P cyclic corrosion.

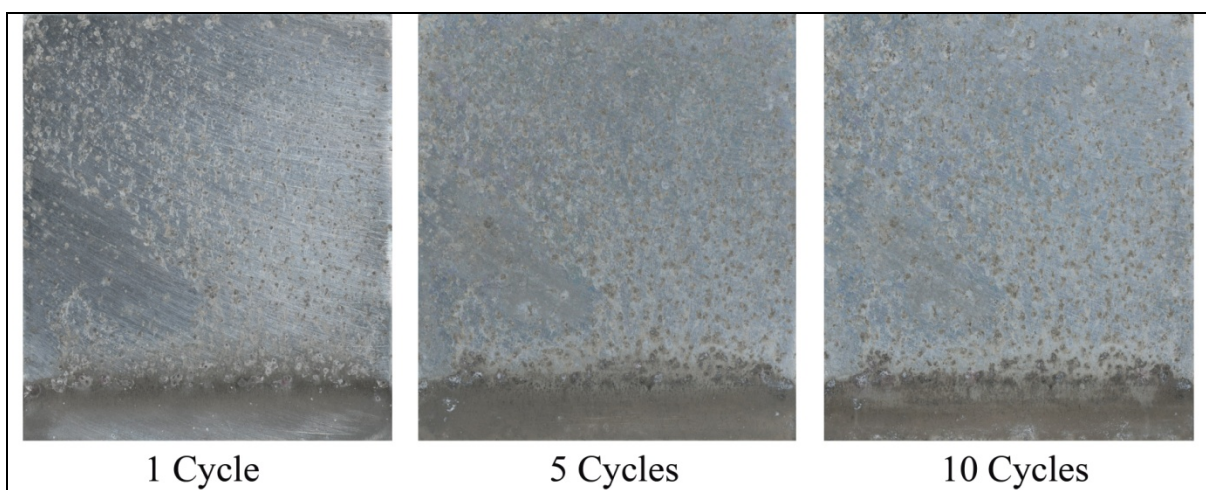


Figure 5. AA2027-T8 after GM 9540P cyclic corrosion.

The 2000-series most documented deficiency in corrosion resistance emanates from pitting attack around copper precipitates. As expected, AA2027 exhibited major surface degradation through extensive pitting and rapid formation of corrosion products and was the least resistant to corrosion of all the alloys in this study. The pitting observed on samples of the T8 temper, exposed to NSF and cyclic corrosion, was shallower and less pronounced laterally across the surface as compared to the T3 temper and perhaps the less severe of the two samples. Overall, AA2027 T8 performed slightly better than most 2000-series alloys examined in the previous U.S. Army Research Laboratory (ARL) study, with the exception of AA2195.

3.2 7000-Series Alloys

Similar to 2000-series aluminum alloys, the 7000-series aluminum alloys are widely used throughout the DOD in aviation applications, missiles, and as ballistic armor plate because of their high strength and stiffness. The recently MILSPEC-qualified AA7085 (appliqué purposed) was examined in its two qualified tempers—T711 (Type A) and T721 (Type B). Two different tempers of AA7056 were also examined and included T7651 and T7351. As with AA2027, AA7056 was originally engineered for aviation purposes; however, its role has been expanded as a possible armor plate material. Also evaluated were T6 and T7 tempers of AA7017, an alloy that has been in use for well over a decade in Europe as an armor plate. Finally, the extruded alloy AA7129-T5, currently used in munitions and automotive applications, was examined. The images in figures 6–19 show the relative corrosion severities sustained on the 7000-series alloys for their respective exposures.

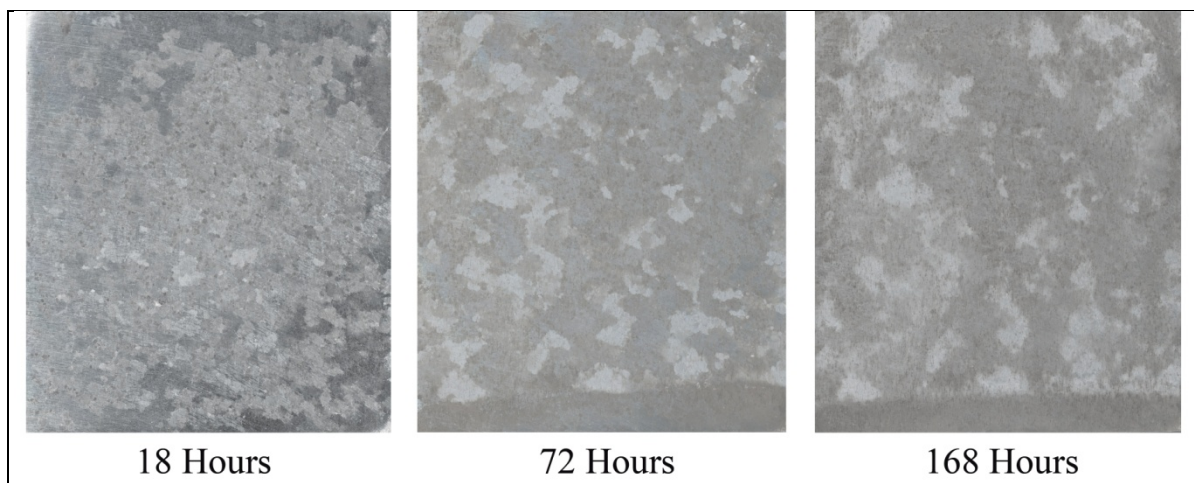


Figure 6. AA7017-T6 after NSF.

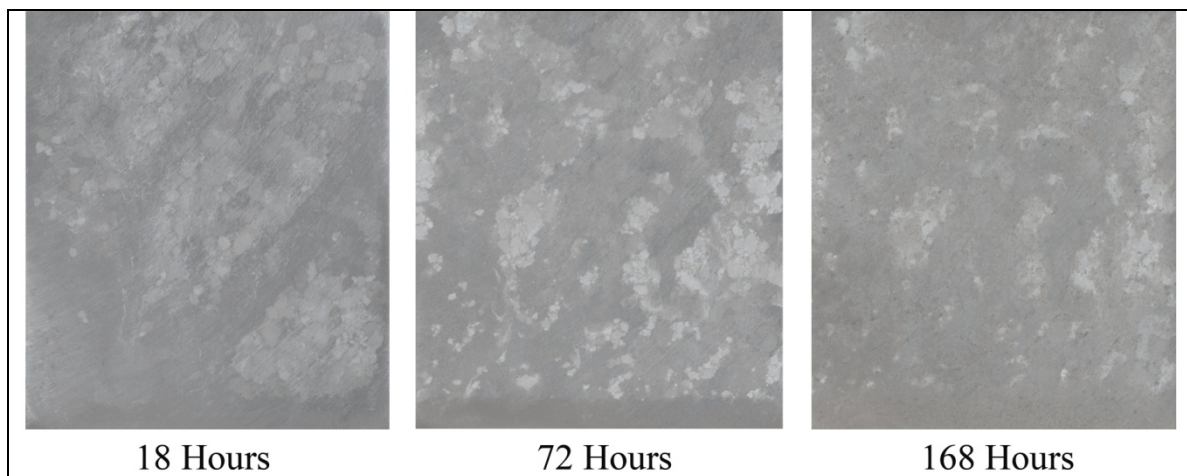


Figure 7. AA7017-T7 after NSF.

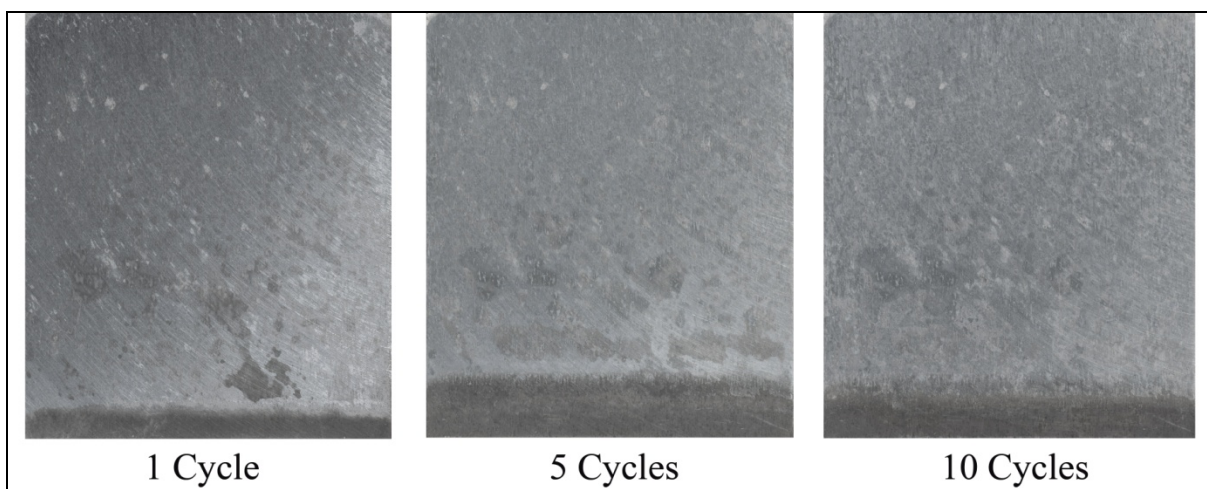


Figure 8. AA7017-T6 after GM 9540P cyclic corrosion.

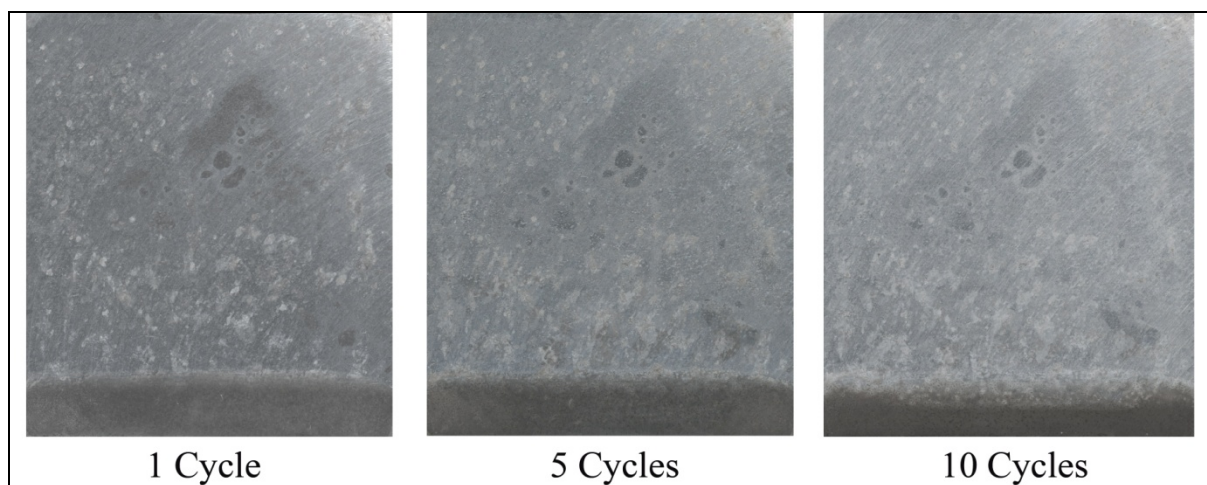


Figure 9. AA7017-T7 after GM 9540P cyclic corrosion.

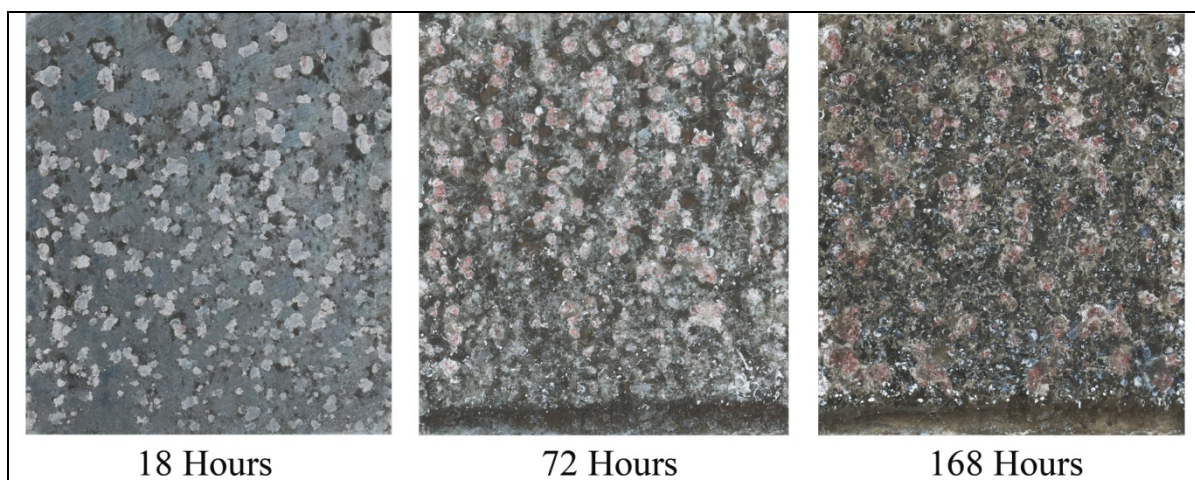


Figure 10. AA7056-T7351 after NSF.

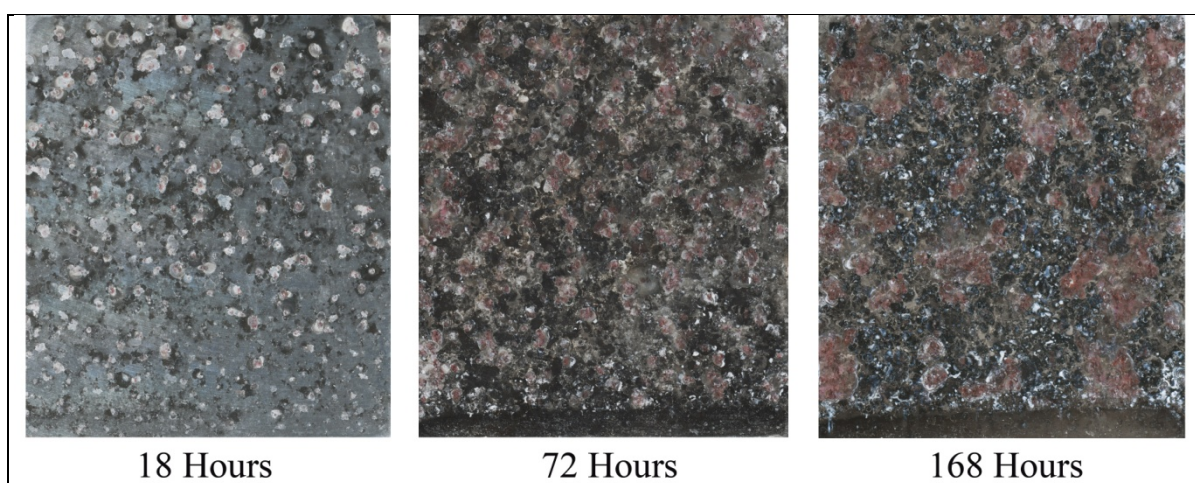


Figure 11. AA7056-T7651 after NSF.

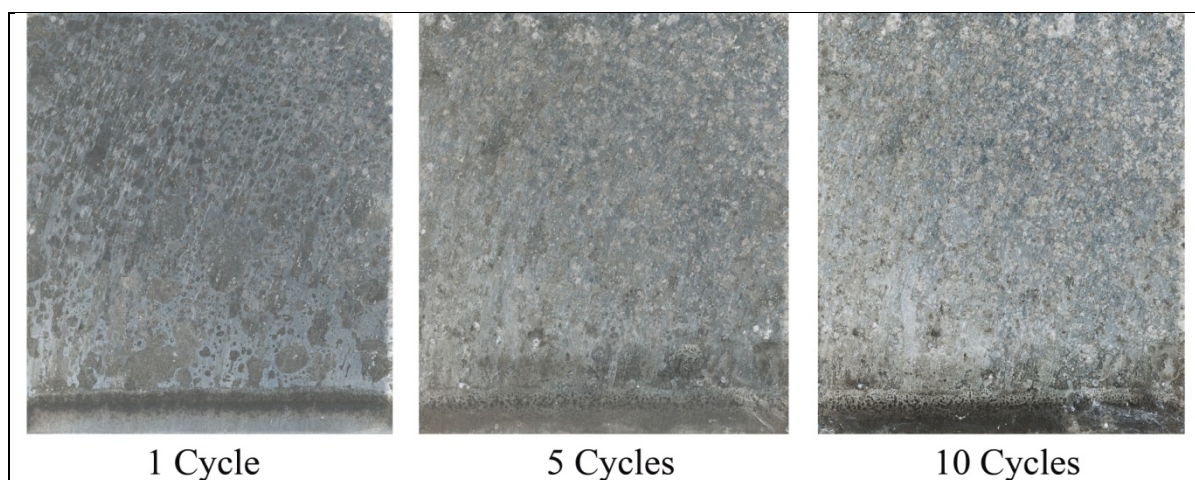


Figure 12. AA7056-T7351 after GM 9540P cyclic corrosion.

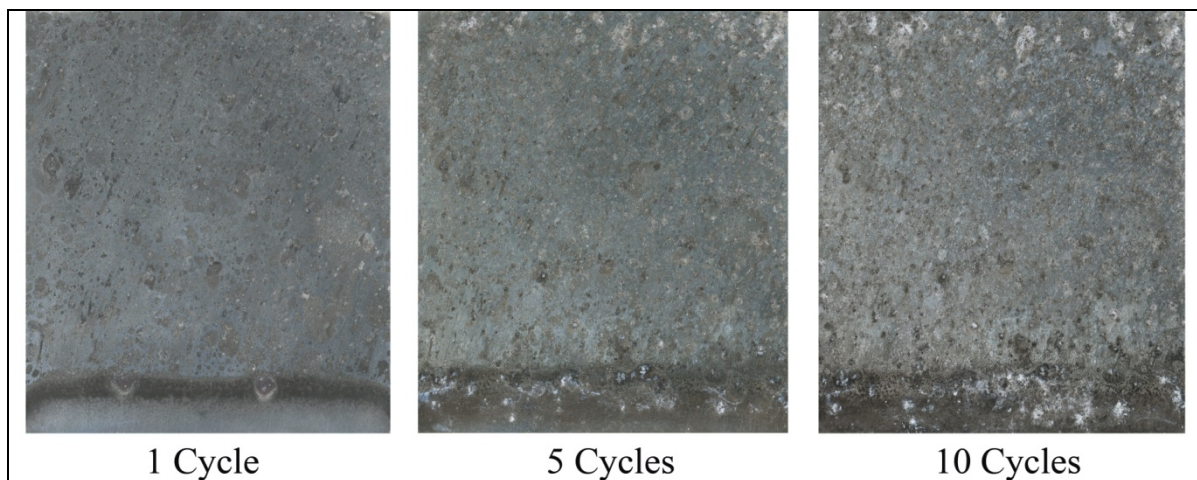


Figure 13. AA7056-T7651 after GM 9540P cyclic corrosion.

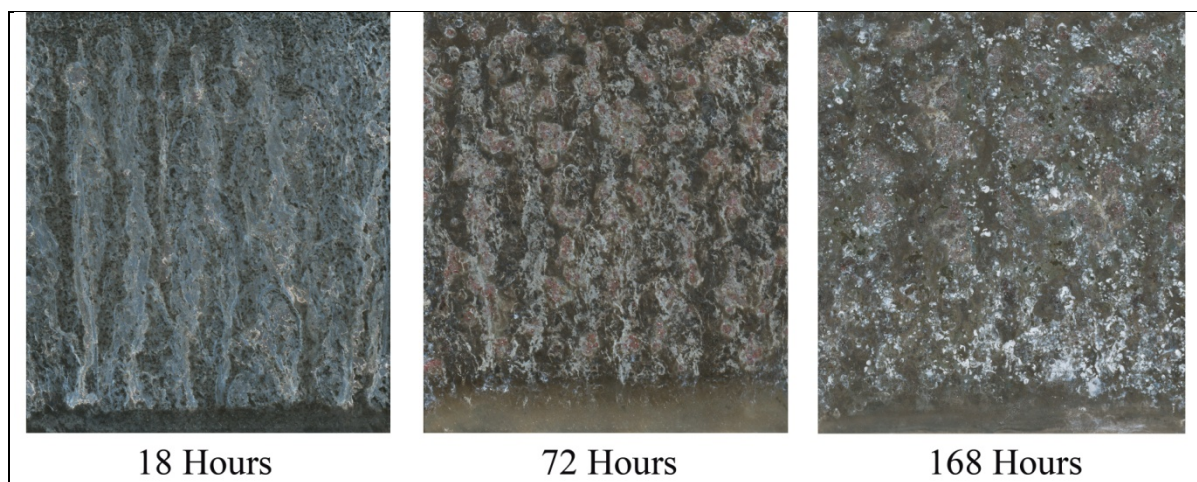


Figure 14. AA7085-T711 (Type A) after NSF.

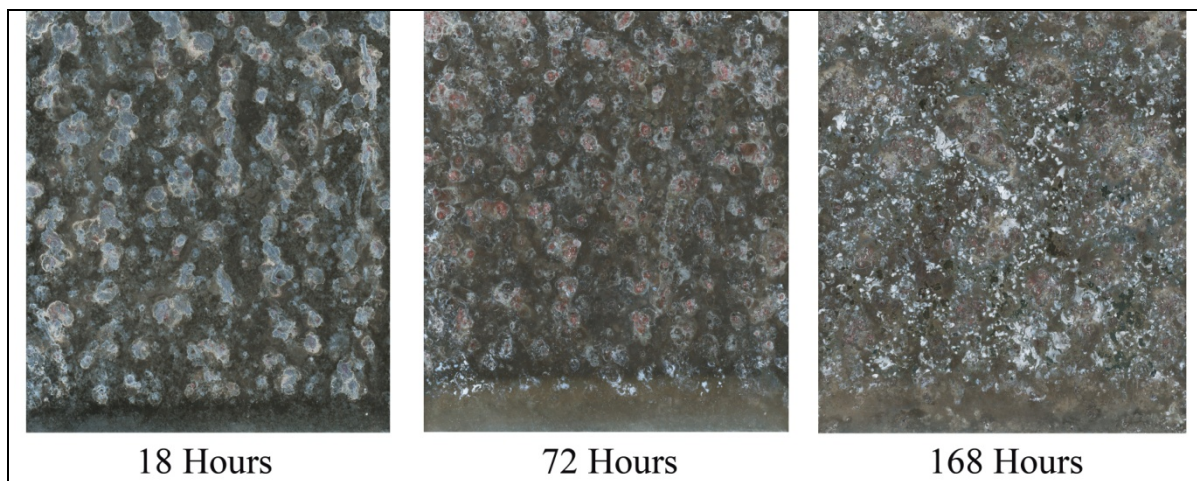


Figure 15. AA7085-T721 (Type B) after NSF.

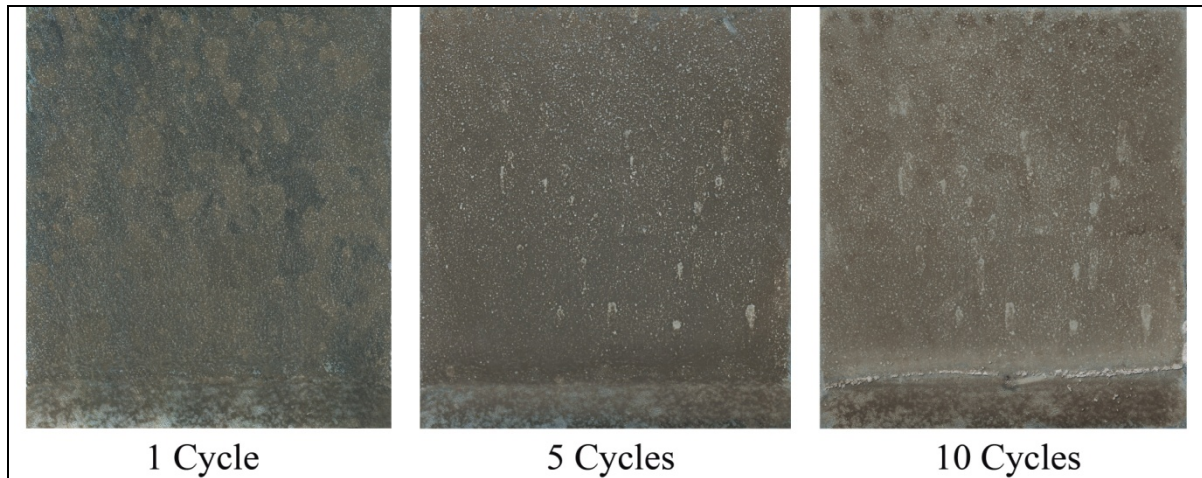


Figure 16. AA7085-T711 (Type A) after GM 9540P cyclic corrosion.

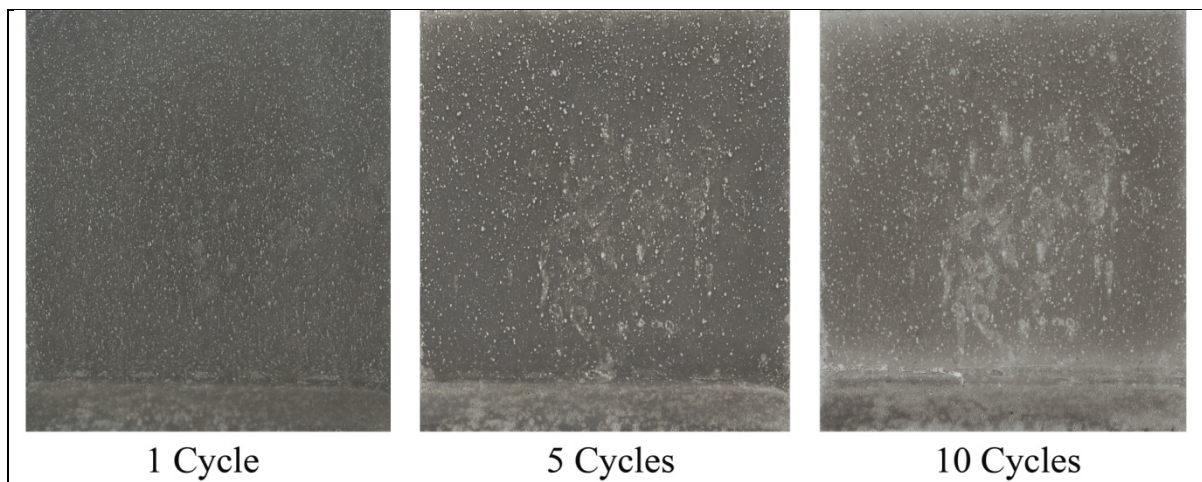


Figure 17. AA7085-T721 (Type B) after GM 9540P cyclic corrosion.

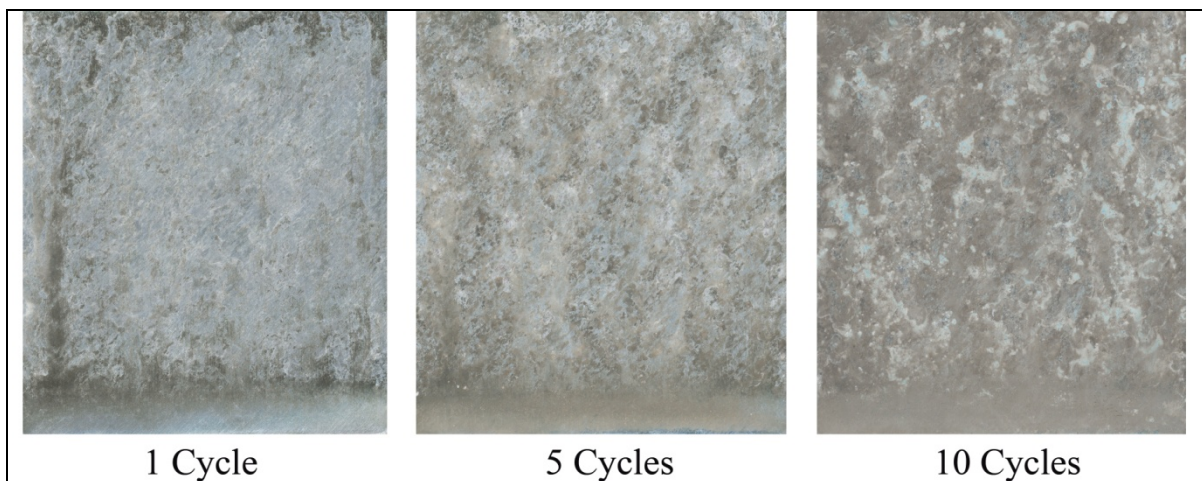


Figure 18. AA7129-T5 after NSF.

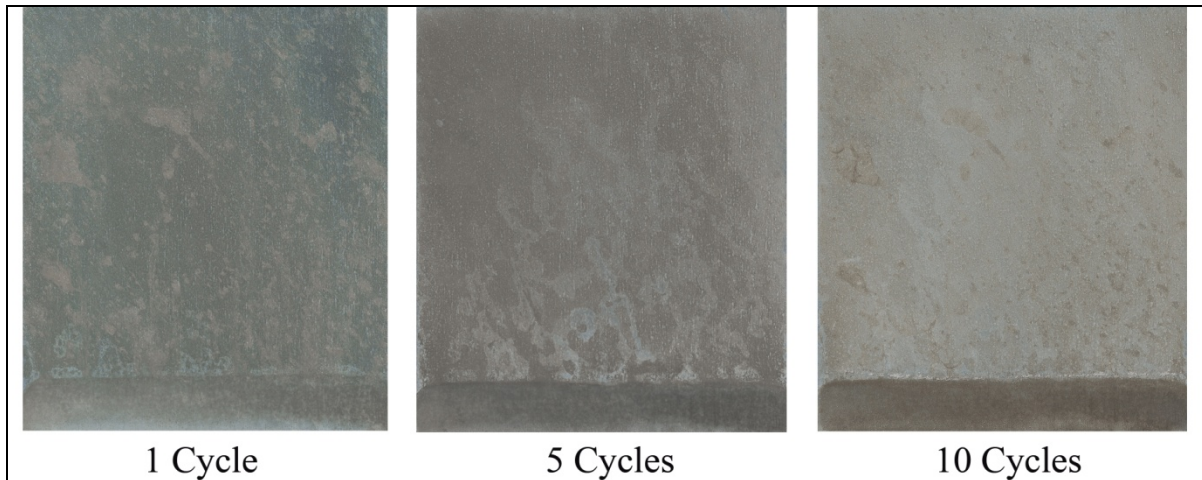


Figure 19. AA7129-T5 after GM 9540P cyclic corrosion.

The 7000-series alloys studied exhibited a wide range of general corrosion damage from significant pitting to practically no pitting corrosion. More specifically, AA7056 and AA7085 exhibited widespread pitting, especially under NSF conditions, and resembled pitting extents seen for many 2000-series alloys under similar exposures. Pitting was also observed for these two alloys under the cyclic exposure—though not nearly as severe as under the NSF. In sharp contrast, the remaining 7000-series alloys, and in particular AA7017, showed very little corrosion. Under NSF the extent of the corrosion damage for both AA7017 tempers was mild etching that revealed a morphology resembling the grain structure of an etched alloy. The corrosion produced under cyclic exposure was even less severe for the AA7017 tempers and only appeared as surface stains. The general corrosion of AA7129 was also minimal, yet could be considered more severe than AA7017. Both AA7129 and AA7017 were significantly more corrosion resistant than their counterparts from the tempers of AA7056 or AA7085. Although not a formal objective in this study—but in deference to previous observations of instances of unanticipated edge cracking (figure 20) on armor plate corrosion specimens—no cracking was observed on the edges of any of the alloys examined.

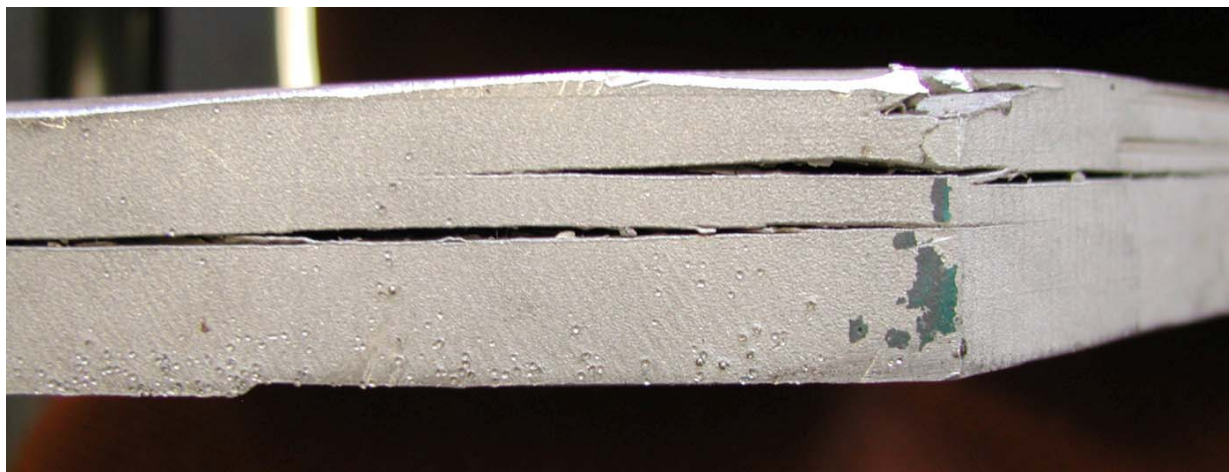


Figure 20. Short-transverse edge cracking of AA7039-T64 armor plate.

3.3 Removal of Corrosion Products

After optical scans of the corroded specimens were collected, the substrates were immersed in the cleaning solution to remove the corrosion products on the surface. After the cleaning was completed, the substrate surface was free of corrosion products revealing the degree of corrosion damage from the accelerated corrosion exposure. Optical scans of the cleaned specimens, including magnified images of select alloys, were recorded and are arranged in figures 21–23. The cleaning removed all of the corrosion products with the exception of the T351 temper of NSF-exposed AA2027, which revealed interesting dark streaks that run parallel to the rolling direction. These elongated stains were unique to the NSF specimen and were not observed for the AA2027-T3 sample exposed to GM 9540P cyclic corrosion testing—or any of the other alloys or tempers under either exposure. The cleaning further revealed deep pitting among AA2027, AA7056, and AA7085 specimens under NSF with less severe pitting revealed for AA7129. The AA7017 did not pit for either temper in NSF.

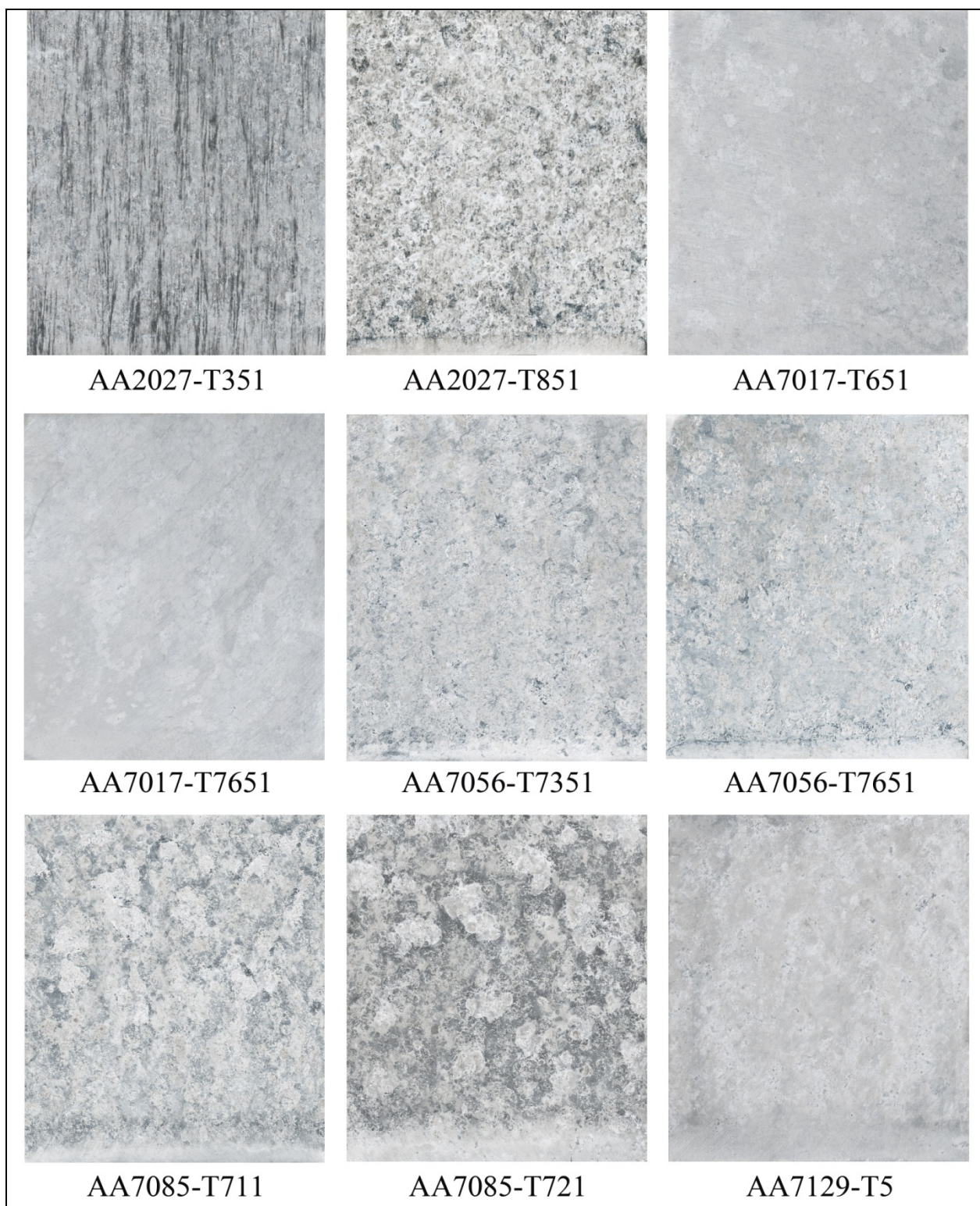


Figure 21. 168-h NSF specimens after cleaning to reveal extent of substrate damage.

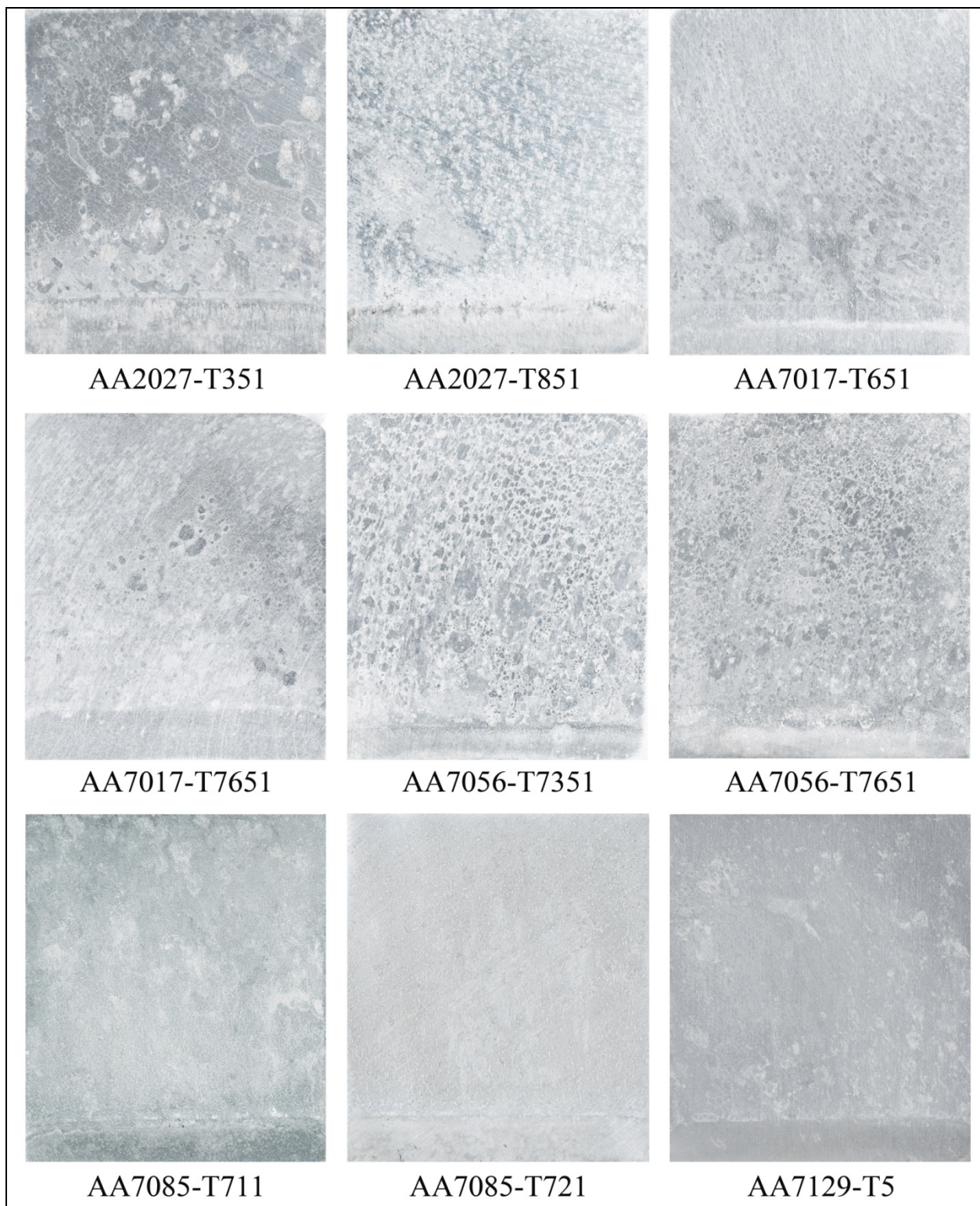


Figure 22. 10-cycle GM 9540P specimens after cleaning to reveal extent of substrate damage.

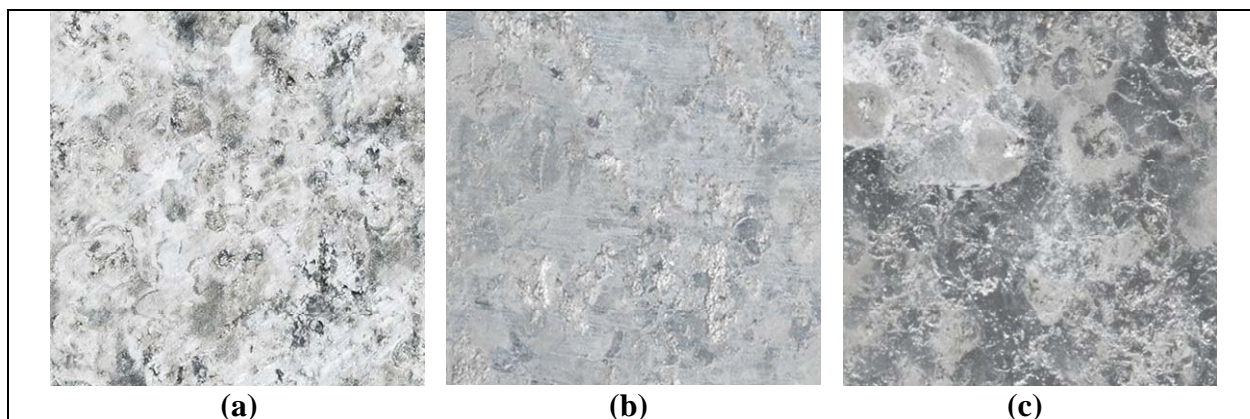


Figure 23. 5 \times magnified images of cleaned (a) AA2027-T8; (b) 7056-T7651; and (c) 7085-T721, revealing substrate loss from pitting potentiodynamic polarization.

3.4 2000-Series Alloys

Polarization curves were used to gauge the corrosion resistance of alloys relative to another. Figure 24 shows the polarization curves of three alloys currently approved for use as armor (MIL-DTL-46092C for AA2519-T8, and MIL-DTL-32341 for AA2139 T8 and AA2195-BT). Although the OCP of each of these alloys is similar, the corrosion if AA2195BT is approximately one order of magnitude less than AA2139 and AA2519. This data suggests that AA2195BT may be more corrosion resistant than the other two alloys.

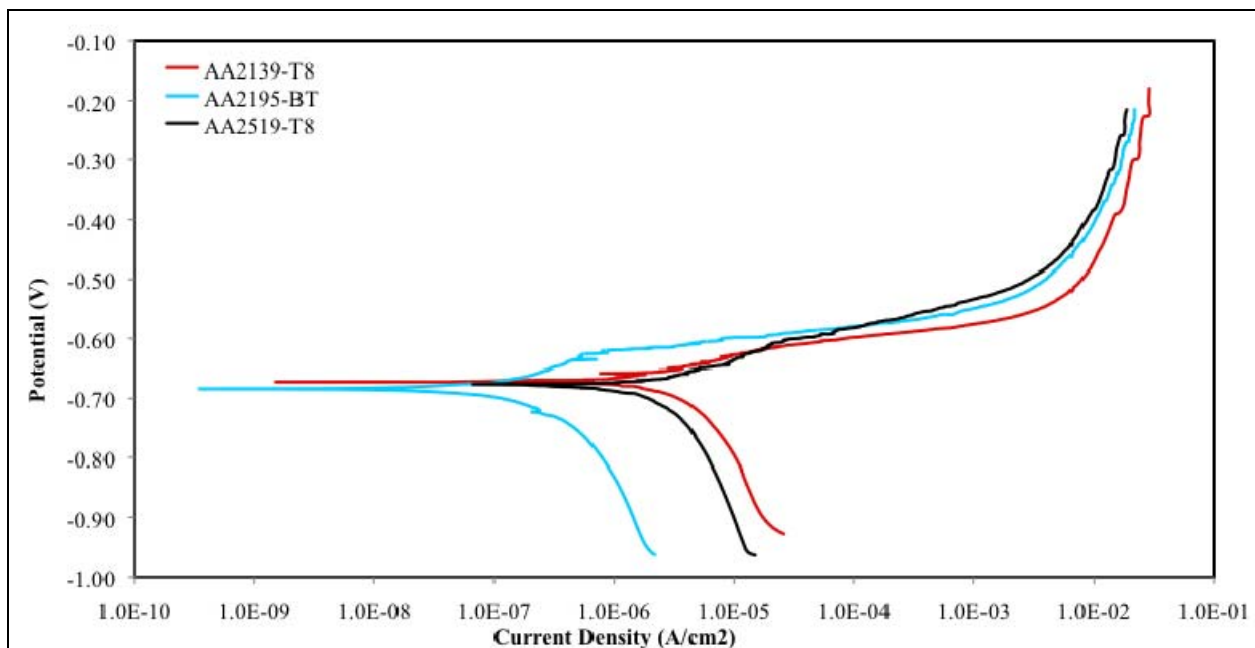


Figure 24. Polarization curves of current 2000-series aluminum armor alloys.

An electrochemical comparison of two different tempers of AA2027—T3 post-rolled natural aged versus AA2139-T8 post-rolled artificial aged—is seen in figure 25. Although the OCP of AA2027-T3 temper is the most anodic, the high corrosion current density and the lack of any form of a passivation event seems to suggest that the AA2027-T3 will be the most corrosion prone of these three alloys in general.

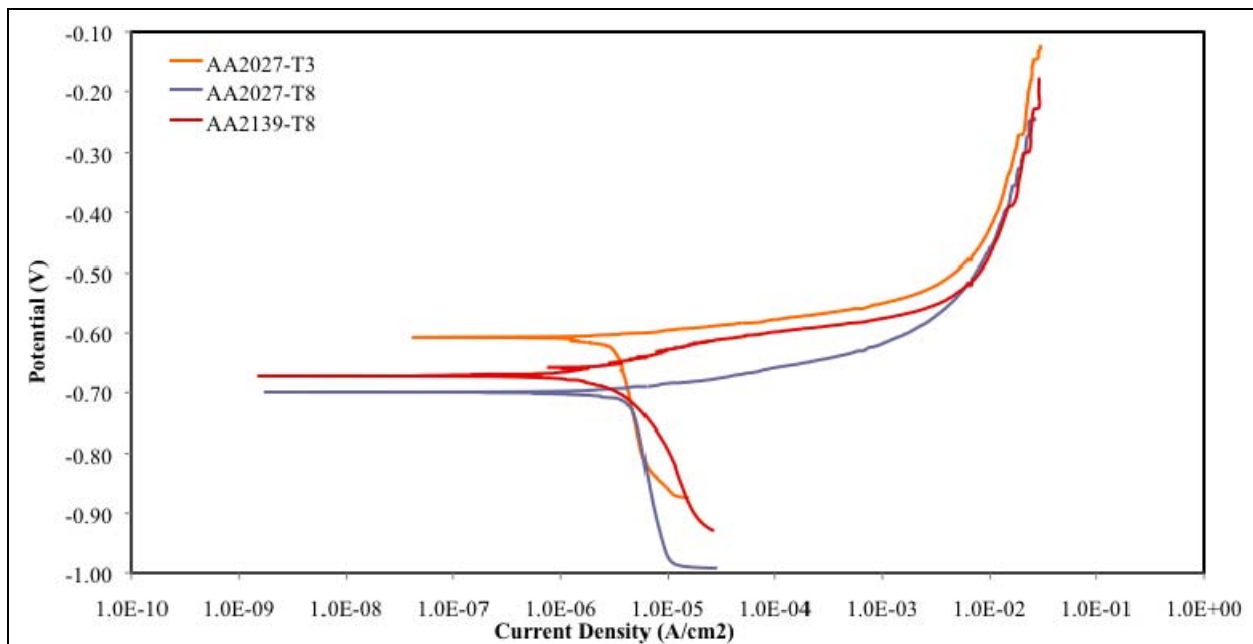


Figure 25. Polarization curve of AA2027-T3 and 2027-T8 compared to AA2139-T8.

Finally, potentiodynamic scans of AA2027-T3 and AAAA2027-T8 were plotted against AA2024-T3 in figure 26 to provide additional basis for comparison against a very well understood alloy. The lowest current densities were observed for AA2024-T3, suggesting it would be the least corrosion prone among the three alloys.

The OCP for all of the AA2027-T3 and AA2027-T8 are summarized in table 5, with readings for current 2000-series armors and AA2024-T3.

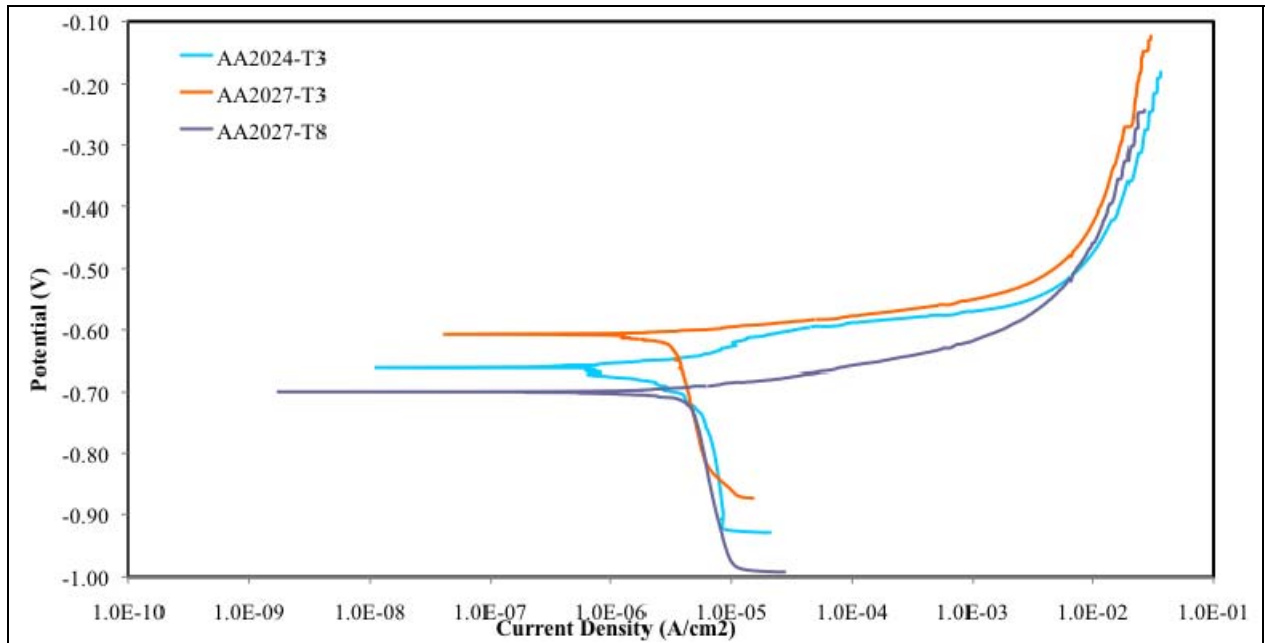


Figure 26. Polarization curves of AA2027-T3 and AA2027-T8 compared to AA2024-T3.

Table 5. Observed OCP readings for 2000-series alloys vs. saturated calomel reference electrode.

Alloy	Open Circuit Potential (mV) vs. Saturated Calomel Electrode
AA2024-T3	-663 ± 8
AA2027-T3	-607 ± 9
AA2027-T8	-700 ± 7
AA2139-T8	-672 ± 11
AA2195-BT	-690 ± 20
AA2519-T87	-684 ± 13

3.5 7000-Series Alloys

Polarization curves were used to gauge the corrosion resistance of the 7000-series aluminum alloys relative to one another. Figure 27 shows the polarization curves of three common alloys from this series. The variation of the OCP of these alloys is approximately 140 mV and the corrosion currents are nearly identical. The data suggests that AA7039-T64 may be more corrosion resistant than the other two alloys.

An electrochemical comparison of two different tempers of AA7017 (T651 and T7651) versus AA7039-T64 is seen in figure 28. Although the OCP of AA7017-T651 is the most anodic, the corrosion current density of AA7039-T65 is slightly less than the other metals. It is unclear from this data alone which of the alloys would be the most corrosion prone.

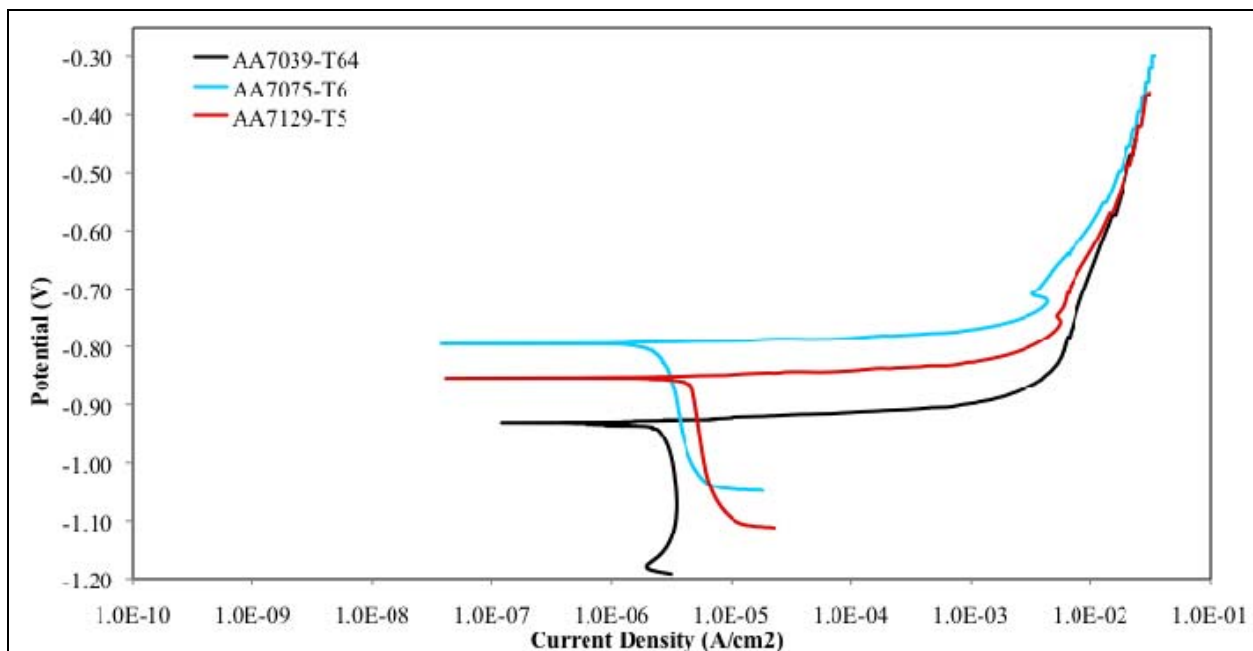


Figure 27. Polarization curves of AA7039-T64 and AA7129-T5 compared to AA7075-T6.

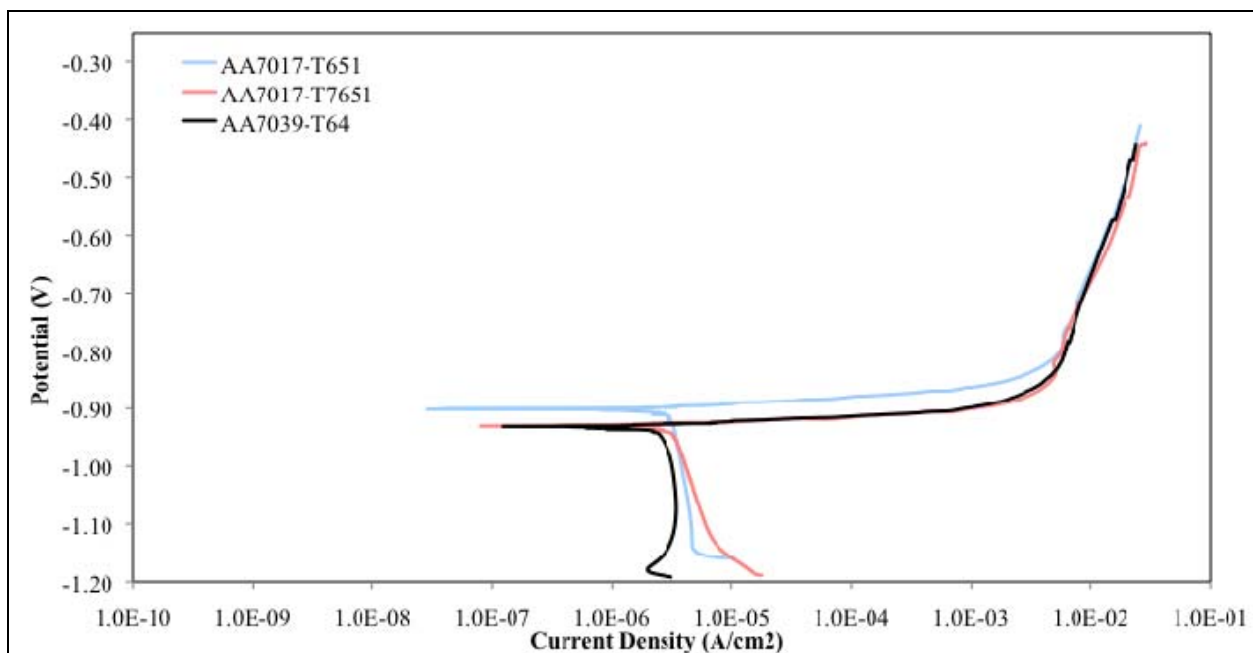


Figure 28. Polarization curves of AA7017 tempers compared to AA7039-T64.

The electrochemical comparison of two different tempers of AA7085 to AA7039-T64 is seen in figure 29. The OCP and corrosion currents of AA7085-T711 and T721 are similar as expected. The OCP of AA7085—particularly the T711 temper—is over 100 mV higher than the OCP of AA7039-T64, yet the similarity in the corrosion current densities make it difficult to predict which alloy will be more corrosion resistant.

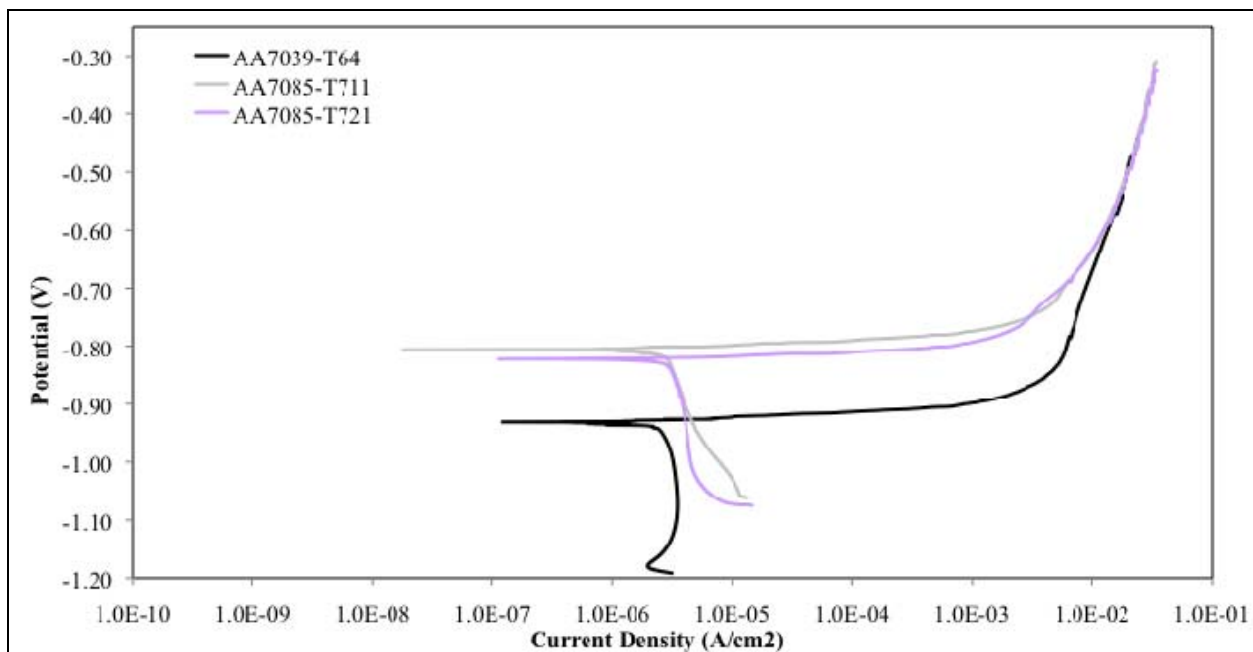


Figure 29. Polarization curves of AA7085 tempers compared to AA7039-T64.

The electrochemical comparison of two different tempers of AA7056 to AA7039-T64 is seen in figure 30. The OCP for both tempers of AA7056 are similar; however, the corrosion current of the T7651 temper is slightly less than the current density of the T7351 temper. The OCP of AA7056, is approximately 100 mV higher than the OCP of AA7039-T64.

The OCP for all of the 7000-series alloys studied are summarized in table 6, with readings for current AA7039-T64 armor and for AA7075-T6.

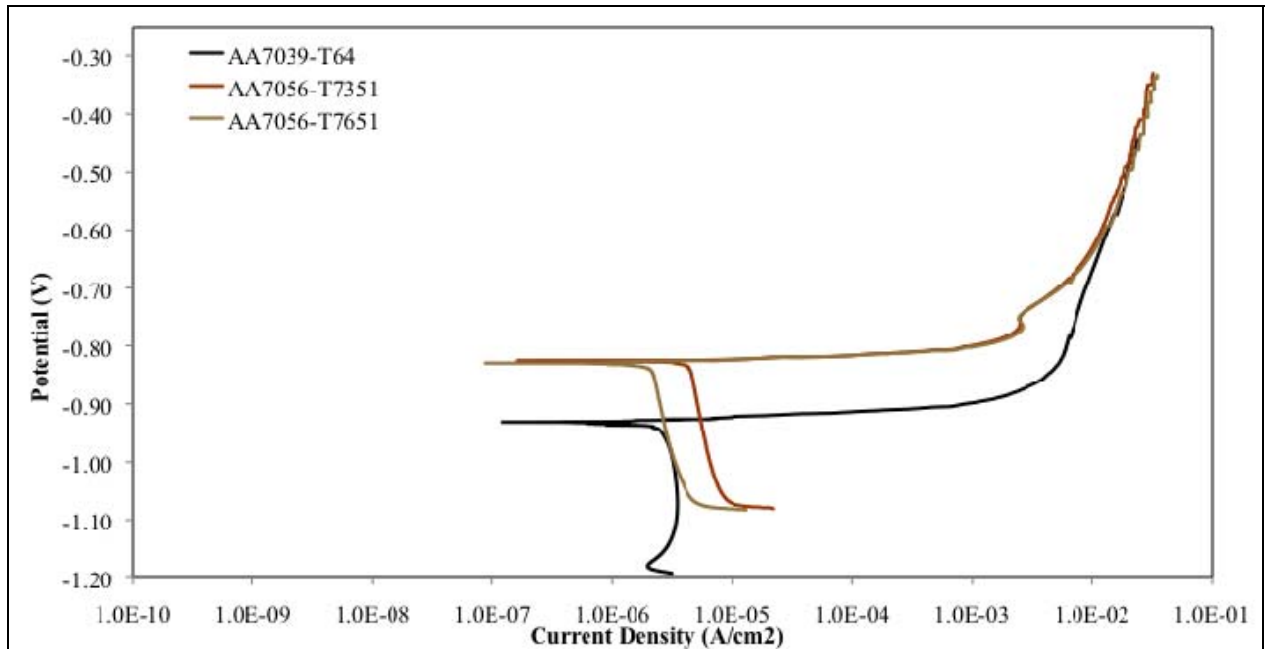


Figure 30. Polarization curves of AA7056 tempers compared to AA7039-T64.

Table 6. Observed OCP readings for 7000-series alloys vs. saturated calomel reference electrode.

Alloy	Open Circuit Potential (mV) vs. Saturated Calomel Electrode
AA7017-T6	-904 ± 14
AA7017-T7	-931 ± 1
AA7039-T64	-929 ± 8
AA7056-T7651	-828 ± 5
AA7056-T7351	-826 ± 6
AA7075-T6	-791 ± 9
AA7085-T711	-806 ± 9
AA7085-T721	-817 ± 8
AA7129-T5	-846 ± 12

4. Discussion

The chamber-based accelerated corrosion methods used in this research provide results that allow for a fast initial screening of the corrosion resistance of aluminum alloys. Between the two accelerated corrosion test methods employed, the NSF exposure corroded the studied alloys more severely than the GM 9540P cyclic procedure. While less severe than NSF, the relative order of amounts of damage observed visually during GM 9540P among the alloy exposures was

in full agreement with the corrosion damage order of severity that was observed under NSF. Additionally, the alloys generally performed as expected under accelerated corrosion with the 7000 series being, overall, more general corrosion resistant than the 2000 series. The AA7056 and AA7085 alloy tempers fared significantly worse in accelerated corrosion resistance when compared to the other 7000-series alloys, and nearly matched the 2000 series for severity of pitting, particularly in NSF. The increased pitting damage was likely due to the much higher copper content in these two alloys. It should be noted that for 7000-series aluminum alloys the biggest drawback has come from their susceptibility to stress corrosion cracking (SCC). Increasing the copper content in aluminum alloys generally decreases this problem and is key for acceptable service life and reduced risk, especially for flight critical applications (18). It is therefore not surprising that despite their outstanding resistance to general corrosion and pitting, the lower copper 7000-series alloys such as AA7039 are prone to SCC (19, 20). Newer 7000-series aluminums—7017, 7056, and 7085—have been designed for improved resistance to SCC. The composition of AA7017 most closely resembles AA7039 and is quite accordingly the focus of ongoing studies for SCC in both tempers due to its low copper content. The truly odd alloy out was AA7129-T5, used only for extrusions that exhibited relatively good corrosion resistance, as would be expected for a structural automotive alloy. The relatively low copper with good overall properties for AA7129 would perhaps make for an interesting and weldable 7000-series armor plate alloy if it was ever considered for rolling.

The intent of this study was to build upon previous work, thereby providing a corrosion evaluation component to what is known about high-performance aluminum alloys that are currently in use, or are likely suitable for use, in U.S. DOD applications. By combining a wide variety of alloys in one study, including alloys currently in use, a relative comparison and qualitative ranking becomes reasonable. Many aluminum-based systems used in both military and civilian applications have been designed specifically with regard to high strength. As previously stated, these accelerated corrosion conditions were used to quickly screen some 2000- and 7000-series alloys. The data should not form the basis for an accurate lifecycle prediction of an alloy's behavior in an actual system to be fielded. Accelerated corrosion data provide reasonable estimations for corrosion resistance that, when accompanied by minimum mechanical property acceptance values, can help system designers define an acceptable starting point for selecting the *best*—not necessarily the strongest—aluminum alloy for their specific application. Furthermore, these comparisons can help guide the selection of applicable coatings systems and/or surface pretreatments based upon service requirements to optimize performance and durability for a specific mission. The addition of corrosion resistance as a selection criterion can potentially offset other factors, such as initial material cost and/or subsequent total cost of ownership, through avoidance of costly repairs due to corrosion.

5. Conclusions

- Of the two laboratory accelerated corrosion methods used, ASTM B 117 NSF caused more severe corrosion across the range of alloys studied when compared to GM 9540P.
- There was agreement between the two laboratory methods across the range of alloys studied.
- Alloys containing greater copper exhibited greater corrosion from pitting.
- Irrespective of temper, AA7017 was the most corrosion resistant in the two accelerated environments.
- Chamber-based accelerated corrosion remains a useful screening tool to rapidly compare aluminum alloys but should not be used for lifecycle prediction.

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List of Symbols, Abbreviations, and Acronyms

AA	aluminum alloy
ARL	U.S. Army Research Laboratory
DOD	Department of Defense
ECBC	U.S. Army Edgewood Chemical Biological Center
GM	General Motors
h	hour
MILSPEC	Military Specification
min	minute
NSF	Neutral Salt Fog
OCP	open circuit potential
SCC	stress corrosion cracking
TMS	The Minerals, Metals, and Materials Society

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